RESEARCH DEPARTMENT

Acoustic characteristics of Maida Vale Studio 1

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THE BRITISH BROADCASTING CORPORATION
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ACOUSTIC CHARACTERISTICS OF MAIDA VALE STUDIO 1

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SUMMARY

This report sketches the history of Maida Vale 1 studio from the time of acquisition by the Corporation. The major difficulty with this studio is the dip in the reverberation characteristic centred at 130 c/s which is shown to be due to vibration of the ceiling and which could be reduced by stiffening the structure. However, in view of the consideration being given to increasing the ceiling height, the expense of stiffening the existing ceiling is not at present justified.

1. HISTORICAL

1.1. Early History

The large orchestral studio, Maida Vale 1, was built inside a former roller-skating rink. Modifications to the original structure were not permitted and the studio had to be designed to fit under the roof line of the original building. The studio walls are built of brick. The ceiling consists of a cross hatch pattern of I-section rolled steel joists suspended from steel roof trusses which fit into the original roof space of the building. Wooden joists rest with their ends in the channels of the rolled steel joists, and carry a lath and plaster inner ceiling skin and are boarded above. The space between the joists and the lath and plaster and boards is filled with wood shavings and sawdust. Two layers of roofing felt were laid on the upper surface of the boards. Initially the internal walls of the studio were completely covered with Celotex building board and no low frequency absorption was applied, nor was the plastered ceiling acoustically treated. Except for a wood block area occupied by the orchestra, the studio floor was carpeted over building board on concrete. The reverberation curve for the studio in its original state is given in Fig. 1, curve (a). (No measurements were available at frequencies below 125 c/s.) Subjectively the studio was excessively live and boomy at low frequencies and dead at higher frequencies.

The addition of an organ and a concert platform in 1936 reduced the reverberation appreciably at low frequencies but had little effect on the reverberation curve at frequencies higher than 700 c/s, Fig. 1, curve (b). The subjective change was negligible.[1]

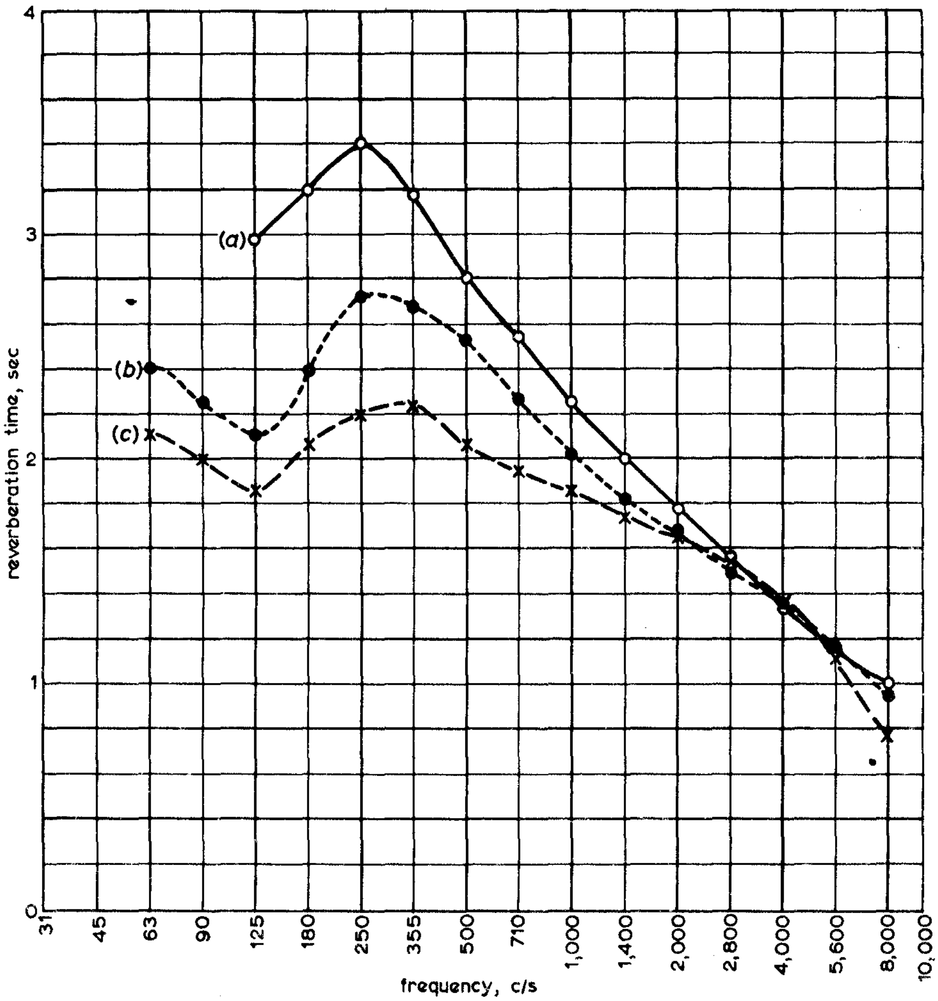

Fig. 1 - Reverberation curves of Maida Vale Studio 1

(a) Studio in its original state
(b) With an organ and concert platform (1936)
(c) With Cabots quilting (1947)

In 1947 additional bass absorption was introduced by hanging Cabots quilting across the ceiling. In an attempt to increase the upper frequency reverberation, the building board was distempered and some of the carpeting in front of the orchestra was replaced by extending the wood block floor a distance of 15 feet (4·5 m). Additional Cabots quilting was hung at the rear end of the studio to eliminate slap-back echo from the rear wall. The reverberation curve under these conditions is shown in Fig. 1 as curve (c). It will be noticed that introduction of Cabots quilting has more than offset the effect of painting the building board and extending the wood block flooring, the net results being a small reduction in reverberation time at high frequencies and a large reduction at low frequencies.

1.2. 1951 Re-Treatment

In 1951 the studio was refurbished and the opportunity was taken of completely renewing the acoustic treatment. The studio walls were almost completely covered with low frequency membrane absorbers whose depths varied from 3 inches (7·6 cm) to 18 inches (45 cm), and in addition to providing low frequency absorption the rectangular shapes of the membrane absorbers provided good diffusion. The Cabots quilting was removed from the ceiling and the effects of the large, highly reflecting surfaces of the ceiling were reduced by fixing rectangular prisms of heights 1 to 3 feet (30 to 90 cm) to the ceiling. No absorptive treatment was added to the ceiling. The Cabots quilting was removed from the rear wall and the wall was treated with triangular-section absorbing units arranged to give a serrated surface which would increase the diffusion. The wood block floor was increased in length by a further 15 feet (4·5 m) and a dado of plywood over rockwool was fitted to the side and rear walls. A larger choir rostrum was provided and in order to eliminate strong reflections from the timpani and brass sections of the orchestra and to maintain approximately constant absorption coefficients for the seats whether occupied or not, padded permanent seats were provided for the choir. The reverberation curves for the studio under these conditions are shown in Fig. 2. Pulsed glide tests and listening

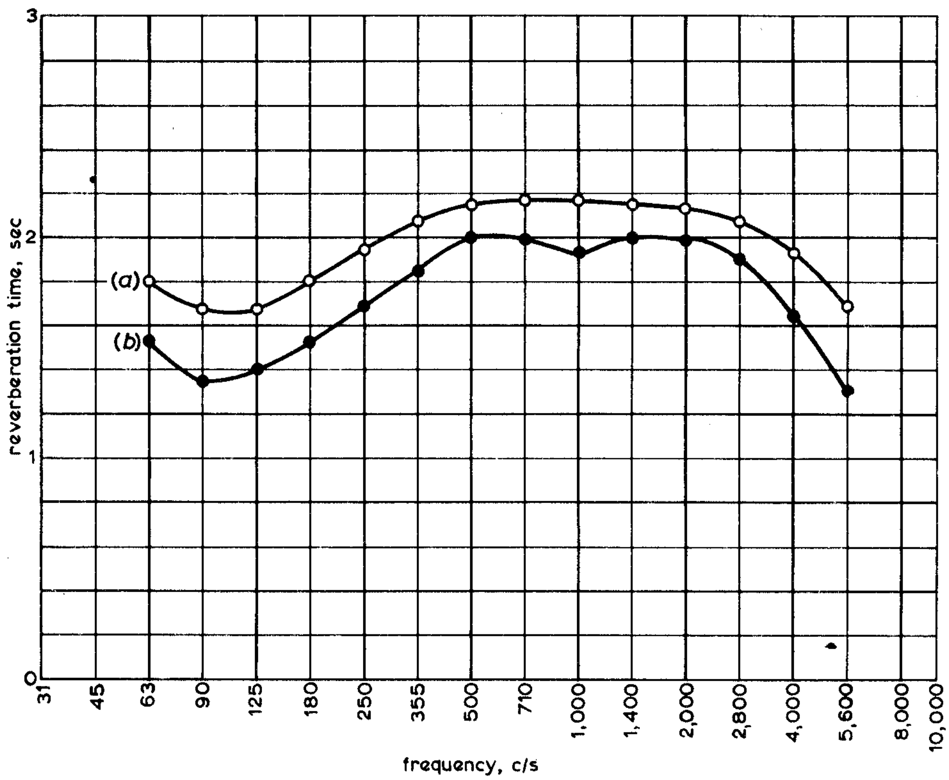

Fig. 2 - Reverberation curves of Maida Vale Studio 1 after re-treatment in 1951

(a) Without rostra and choir seats
(b) With rostra and choir seats

tests showed the studio to be free from colourations, rings and pitch changes. The subjective impressions were that the studio produced sound of warm tone and good definition, while bass masking was negligible. The warmth of tone was attributed to the amount of diffusion present. As can be seen from the reverberation curve, there was a pronounced dip in the reverberation time, centred at about 100 c/s, and this was considered to be the most probable reason for complaints of a lack of 'cello and bass tone. With some orchestral layouts there have also been complaints of weak woodwind tone. These two effects have been investigated at considerable length.

2. WORK IN THE STUDIO SINCE 1951

2.1. Investigation into Lack of Woodwind Tone

In 1958 and 1959 investigations were made to discover the reason for frequent complaints concerning the difficulty of obtaining sufficient woodwind tone in an orchestral ensemble. For many years studio managers had been unable to obtain a satisfactory balance on a single microphone and consequently had to use a second microphone close to the woodwind players. If this was done, the perspective was noticeably incorrect and this often led to the introduction of still further microphones.

When Mr. Rudolf Schwarz became conductor of The BBC Symphony Orchestra, he made several changes in the layout and finished with all the strings on the floor, the woodwind players on the rostrum and the percussion and brass on left and right of the rostrum respectively.

Mr. Schwarz complained that not only was it difficult to hear the woodwind instruments but it was also difficult to carry on a conversation with the woodwind players, though easy with the brass and percussion players on the sides. This seemed to present an opening for the investigation and three methods were used.

(i) Intelligibility tests were made on speech with the speaker in the positions of various players and the listener on the conductor's rostrum. The presence of other orchestral players between the speaker's and listener's positions was simulated by rolls of Hylotex wrapped round microphone and cue-light stands. Intelligibility tests were made both in the studio (binaural) and from recordings afterwards in a listening room (monaural conditions).

These tests showed that the intelligibility of words and sentences at the conductor's position was significantly lower from the middle of the woodwind area than at two other places at substantially the same distance. Both monaural and binaural listening produced this result. Female voices produced a less significant difference than male.

(ii) Subjective and instrumental measurements were made of the loudness at the rostrum of the sound of a clarinet played in various locations. These tests gave uncertain results owing to the inherent variability of the signal, but tended to suggest that the height of the player above the rostrum was of more importance than his plan position in the studio. Screens representing other orchestral players reduced noticeably the loudness when the source of sound was low.

(iii) Short-pulse displays were obtained with the microphone in various orchestral positions and the loudspeaker in the conductor's position. In the first series of tests there appeared to be a systematic difference between the good and bad positions in the orchestra, but subsequent tests failed to verify this.

The only positive outcome from these tests was that it appeared desirable to place the woodwind players on a higher rostrum so that they would be above the level of the players in front of them.

New rostra incorporating this and other modifications were therefore installed. Subjectively the result was an improvement though still not altogether satisfactory.

2.2. Investigation into the Cause of the Low Frequency Dip in the Reverberation Curve

2.2.1. Preliminary study of bass absorption

It was pointed out in 1952 that the most probable cause of the dip in the reverberation curve at low frequencies was structural absorption. Tests were made over a period of several years to explore this possibility but no surfaces such as panelling, rostra, etc. of sufficient area were found with resonances at the appropriate frequencies.

The following possibilities received detailed attention:

(i) Absorption by rostrum, panelling, etc. The resonance frequencies and Q factor of every type of panelling were measured. There were eleven different types of panelling with a total area of 4,500 ft^2 (410 m^2). Of these, only four types, totalling approximately 2000 ft^2 (185 m^2) in area, showed resonances in the appropriate region. To account for the observed absorption in the studio, the whole of this area of 2000 ft^2 (185 m^2) would have to absorb with an absorption coefficient of approximately unity from 80 c/s to 200 c/s, but most of the area had a Q factor exceeding 20, implying an absorption bandwidth in the middle of the frequency range of only 7 c/s. Clearly, then, vibration absorption in the panelling and rostrum is insufficient as an explanation of the low frequency dip in the reverberation curve.

(ii) Absorption by the Organ. Special attention was paid to the organ because the dip in the reverberation characteristic was first noticed after the installation of the organ. Three methods of test were used. In the first, the reverberation characteristic of the studio was measured with the swell shutters open and then completely closed. These shutters are constructed of 1-inch (2·5 cm) thick solid timber and present a considerable barrier to the passage of sound.

The measurements showed a slight difference only in the total absorption but the dip in the reverberation curve remained unaltered.

Secondly, a microphone was introduced into the organ chamber, and measurements of reverberation time carried out. These showed that the reverberation time in the chamber was similar to that of the studio as a whole at middle frequencies, but higher, i.e. without the pronounced dip, in the region 50 to 200 c/s. There is thus no important absorption in this region within the chamber.

Lastly, insulation measurements from outside to inside of the organ case showed that even with the shutters open, the coupling with the studio was not great enough to account for very high absorption coefficients.

The area of the whole organ front is approximately 600 ft^2 (54 m^2) and it would be quite impossible for it to account for even a substantial fraction of the 2000 Sabins* (185 M.K.S. units) of unaccountable absorption.

2.2.2. Absorption by the Ceiling

The only structure remaining that might account for the sound absorption appeared to be the ceiling, but it was felt that this was too massive a structure to respond to the ambient sound pressures. However, further theoretical consideration in 1962 indicated such a possibility, provided that the mechanical constants of the ceiling had suitable values. A series of experiments was therefore started.

In the first, warbled tone was radiated from a loudspeaker in the studio and the frequency varied slowly from 50 c/s to 500 c/s, a band extending more than an octave beyond each side of the dip. Observers were stationed in the roof space above the ceiling and, during the run, pronounced sound reinforcement was heard at about 150 c/s.

The ceiling was then excited with a series of hammer blows and in the auditorium a strong colouration was again noticed at 150 c/s. An accelerometer was then attached to the upper surface of the studio ceiling and the amplified output from the accelerometer pick-up was applied to the LSU/10. As the loop gain was increased acoustic howl-round was produced at 147 c/s and a further increase of gain changed the howl-round frequency to 103 c/s. The loudspeaker was then fed with the amplified accelerometer output in parallel with the tone source output. The frequency of the tone was varied from 80 c/s to 400 c/s and maxima in the accelerometer output were again observed at 103 c/s and 147 c/s. From these measurements simplified calculations gave the following results:

(a) Assuming the dip in the reverberation curve to be due to extra absorption provided by the ceiling, then the peak absorption coefficient at resonance frequency due to vibration of the ceiling must be 0·22 and the acoustic resistance r must be 760 c.g.s. units.

(b) For the ceiling, 'Q' $= \dfrac{2\pi f_o m}{r}$

$= 26$, where m = mass/unit area of ceiling

(c) The bandwidth would then be 6 c/s, the build-up time about 0·16 sec, and the decay time about 0·36 sec.

The decay time for the ceiling is very much less than the reverberation time in the studio and so the ceiling could well absorb sound energy, reducing the reverberation time. This experiment suggested that if the ceiling vibrated in several modes with natural frequencies in the range of 80 c/s to 300 c/s, each mode having a bandwidth of the order of 6 c/s, then the dip in the reverberation curve could be attributed to vibrations in the ceiling.

* One Sabin is the equivalent absorption of one ft^2 of perfect sound absorber.

2.2.3. Vibration Studies on the Ceiling

The microphone was hoisted to a position as close as possible to the studio ceiling, an accelerometer was attached to the upper surface of the ceiling immediately above the microphone, and recordings of microphone and accelerometer outputs were made for each of eight positions. Analysis of corresponding recordings showed that a series of maxima in the accelerometer output occurred when the sound pressure had corresponding minima. The bandwidth of the peaks appeared to be of the order of from 5 to 7 c/s. To study this effect with greater precision a logarithmic difference amplifier was designed and made. This will be described elsewhere. Fig. 3 shows a typical result in which the accelerometer output in relation to the sound pressure 4 feet (122 cm) from the loudspeaker is plotted against frequency.

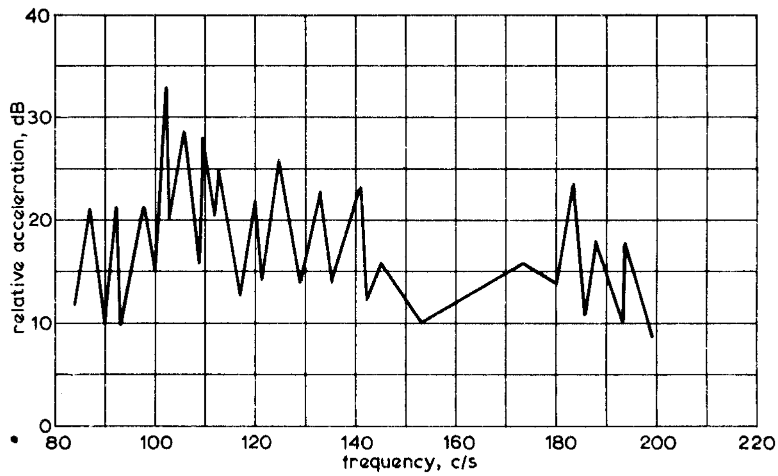

Fig. 3 - Acceleration amplitude of ceiling relative to the sound pressure level in the studio. Excitation by sound from loudspeaker

This again shows sharply defined modes of vibration of the ceiling in the frequency range 90 to 200 c/s.

The sound insulation between the studio and the roof space, that is, the insulation provided by the ceiling, was measured by the method recommended in B.S. 2750:1956 in which the sound pressure level inside the studio and in the roof space was compared at five positions close to the ceiling. Curve (a) of Fig. 4 shows the results and superimposed on it is the reverberation curve (curve (b)). It will be noted that in the region of the dip in the reverberation curve the insulation provided by the roof shows a minimum. These measurements again indicate vibration of the ceiling in the frequency band 80 to 300 c/s.

A vibration generator was then placed on various panels of the ceiling and an accelerometer was attached to other panels of the ceiling. The frequency of the tone applied to the generator was varied and the response of the accelerometer was recorded and analysed. The recordings again show peaks in the response, and the response irregularity in the 80 to 300 c/s region (see Fig. 5) was much greater than at higher frequencies.

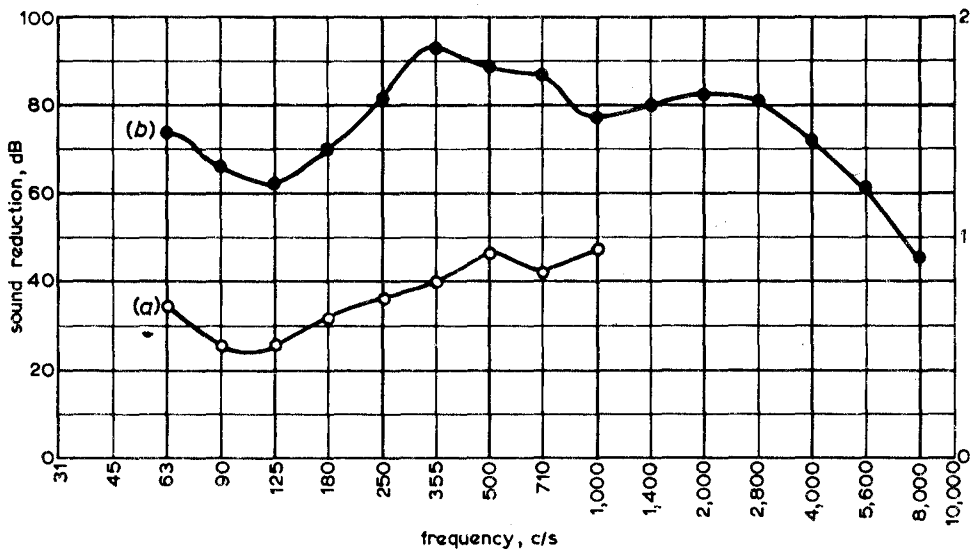

Fig. 4 - Comparison of reverberation time with sound reduction index of ceiling

(a) Sound reduction provided by the ceiling
(b) Reverberation curve

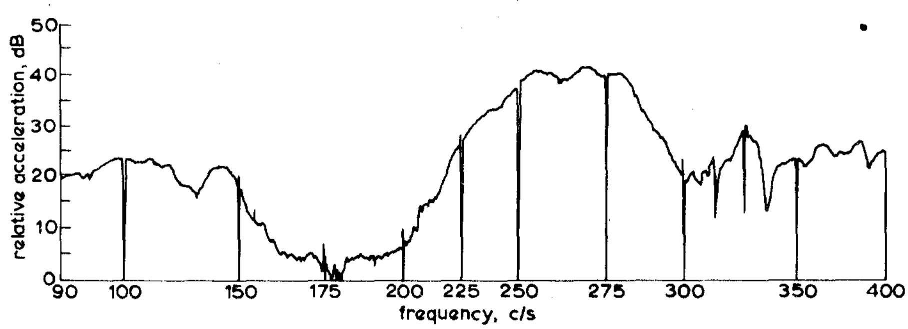

Fig. 5 - Variation, with frequency, of acceleration amplitude of a ceiling panel

2.2.4. Possibility of Reduction of Absorption by the Ceiling

These investigations confirmed that ceiling resonances could be the cause of the dip in the reverberation characteristic. Their effect could be reduced by loading or stiffening the ceiling. Loading would reduce both the amplitude and frequency of the resonances, but was considered impracticable on account of load-bearing considerations. Stiffening would reduce amplitude and raise resonance frequencies, thus causing a reduction of reverberation time in a more acceptable frequency region.

It was therefore decided that one of the panels of the ceiling should be experimentally stiffened. To do so it was necessary to remove from the upper surface of the ceiling the breeze blocks which had been laid at the beginning of the war as a precaution against incendiary bombs. The reverberation time was then taken with the ceiling in its original state. This, as can be seen from Fig. 6, was little different from previous reverberation curves.

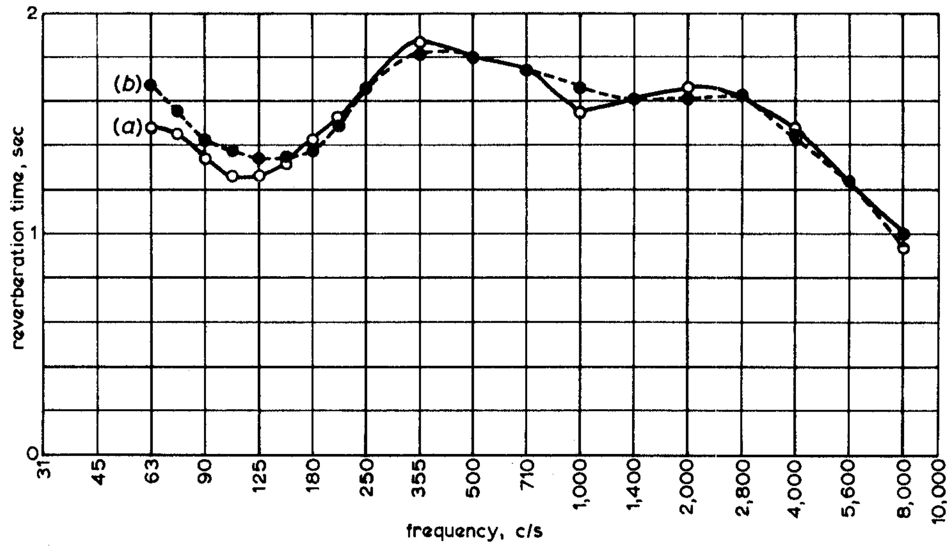

Fig. 6 - Reverberation curves of Maida Vale Studio 1

(a) Before removal of breeze blocks from upper surface of ceiling
(b) After removal of breeze blocks from upper surface of ceiling

2.2.5. Model Experiment

Before experimenting on the ceiling, it was decided to make further experiments on a model of a section of the ceiling which could be used also to find the best method of stiffening the structure. A model of one ceiling panel was therefore constructed at a scale of one-eighth. Fig. 7 is a photograph of this model. Excitation was applied at each of three points on its surface by means of a small vibration generator and for each of the three points of excitation the response was measured at four points by an accelerometer. The measurements were repeated after stiffening the model with eleven diagonal beams. Typical results are shown in Fig. 8, from which it will be seen that the stiffening greatly reduced both the absolute vibration amplitude and also the amplitude at low frequencies in relation to that at high frequencies.

2.2.6. Conclusion of the Investigation

As a result of this model experiment, it was decided to go ahead and stiffen one panel of the roof. Measurements were made of the response of the panel both before and after stiffening and the results were in agreement with those of the model experiment, showing that the frequency discrimination had been reduced, Fig. 9.

It thus appeared that the low frequency dip in the reverberation curve of Maida Vale Studio 1 could be reduced and perhaps eliminated by stiffening the ceiling. This would have been costly and the work was held in abeyance pending a decision.

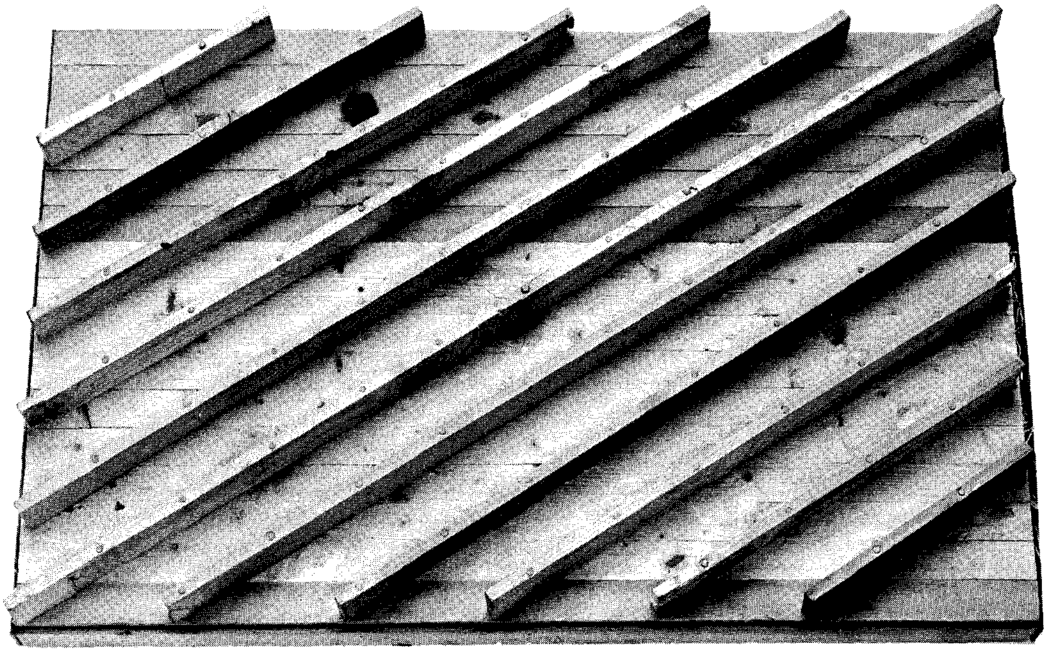

Fig. 7 - Photograph of a one-eighth scale model of a ceiling panel of Maida Vale Studio 1

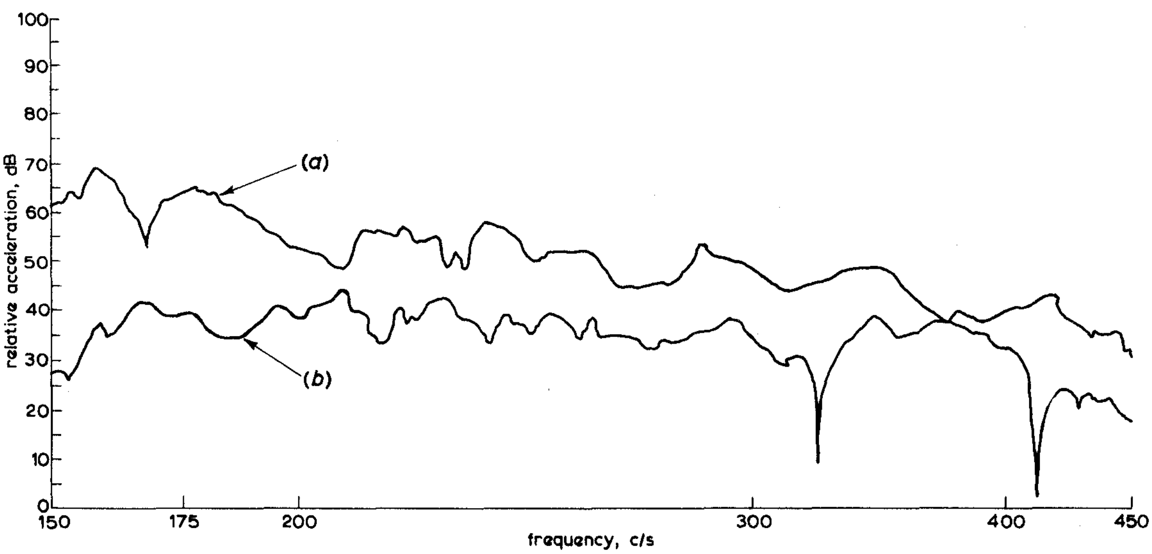

Fig. 8 - Acceleration amplitude at a point on a one-eighth scale model of a roof panel when excited by a generator at a second point

(a) Before stiffening
(b) After stiffening

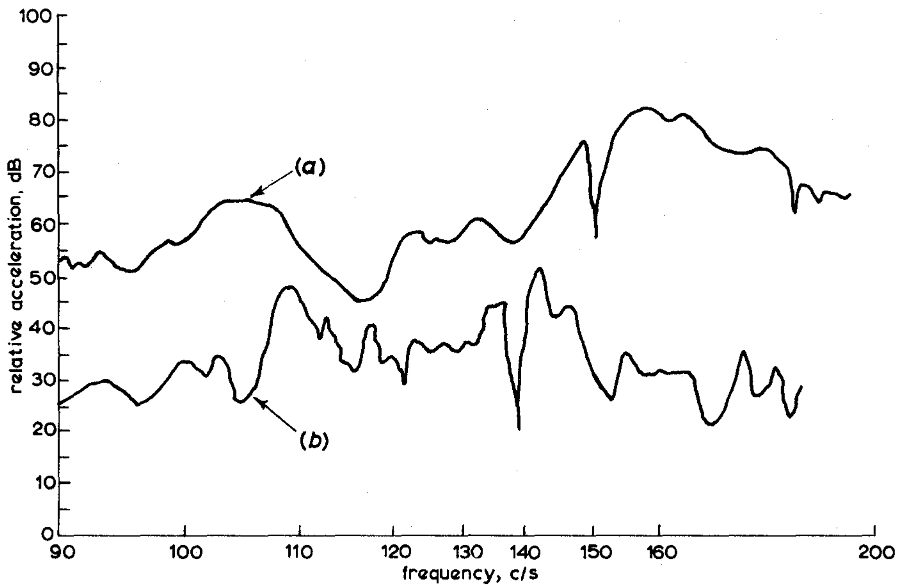

Fig. 9 - Acceleration amplitude of a ceiling panel at a point when excited by a vibration generator at a second point

(a) Before stiffening
(b) After stiffening

Meanwhile a decision had been taken by Music Department to increase the studio audience to about double the previous size and this necessitated an increase in the capacity of the ventilation plant. In order to accommodate the new ventilation distribution ducts in the studio, most of the bass absorption units were removed from the two sides of the studio. The reverberation times were increased in these circumstances, see curve (a), Fig. 10, and re-treatment was recommended accordingly.

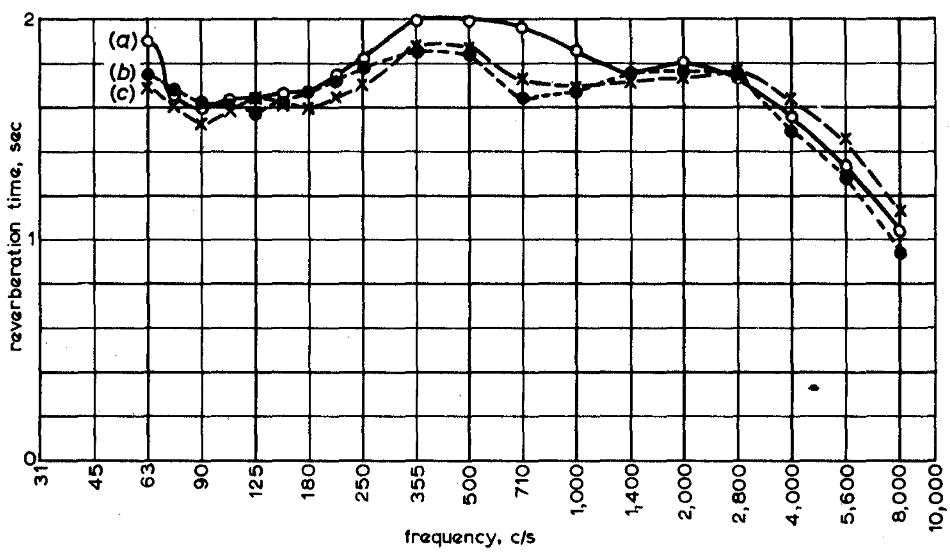

Fig. 10 - Maida Vale Studio 1, reverberation curves 1963

(a) Without orchestral rostra and with bass absorbers removed from both side walls
(b) After re-treatment, with no orchestral rostra
(c) After re-treatment, with orchestral rostra in place

The suggestion was made that the low frequency absorbers should not be replaced but that mid-frequency absorbers, consisting of 20% perforated hardboard over 1-inch (2·5 cm) of Therbloc above a 2-inch (5 cm) airspace, should be applied over the surfaces of all the new ventilation ducts. This was done and the reverberation curves were obtained both before and after installation of the new permanent rostra. The curves are shown respectively as (b) and (c) in Fig. 10. Subjectively the studio seems to be much more live, particularly in the frequency region occupied by the lower strings.

3. CONCLUSIONS

There has been continuous effort to improve the acoustics of Maida Vale Studio 1 since it was acquired by the Corporation. Extensive experiments, both on a scale model of the ceiling and in the studio, have indicated that a large amount of absorption in the low frequency region is provided by vibration of the ceiling structure. The investigations suggest that the effect of this could be eliminated by bolting wooden and steel joists on to the upper surface of the ceiling. Recently the studio was taken out of service to be equipped with an improved ventilation system. During these operations, the opportunity was taken of removing some low frequency absorption units from the walls in order to offset, to some extent, the structural absorption provided by the ceiling. At the present time consideration is being given to increasing the ceiling height, and in view of the expense, stiffening the existing ceiling would not be justified if it is to be raised at a later date. Since an audience of some 200 to 300 people is envisaged during orchestral broadcasts from Maida Vale Studio 1, an increase in the ceiling height of some 50% would considerably improve the acoustics.

Assuming that the ceiling height is to be increased by 50%, the volume of the studio would be 330,000 ft^3 (9,500 m^3); for this volume a suitable reverberation time would be 1·95 sec. The ceiling would be provided with large discontinuities of surface to ensure good diffusion of sound in the studio. The natural modes of vibration of the structure would be highly damped and the ceiling would be stiff enough to ensure that it would not respond to excitation by sound pressures in the studio.

4. REFERENCE

1. Technical Note on the Acoustic Re-Treatment of Maida Vale Studio 1, Research Department, November 14th 1951.

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